Micromorphology of Ash-Mantled Soils in Udic & Xeric Moisture Regimes of Blue Mountains, OR

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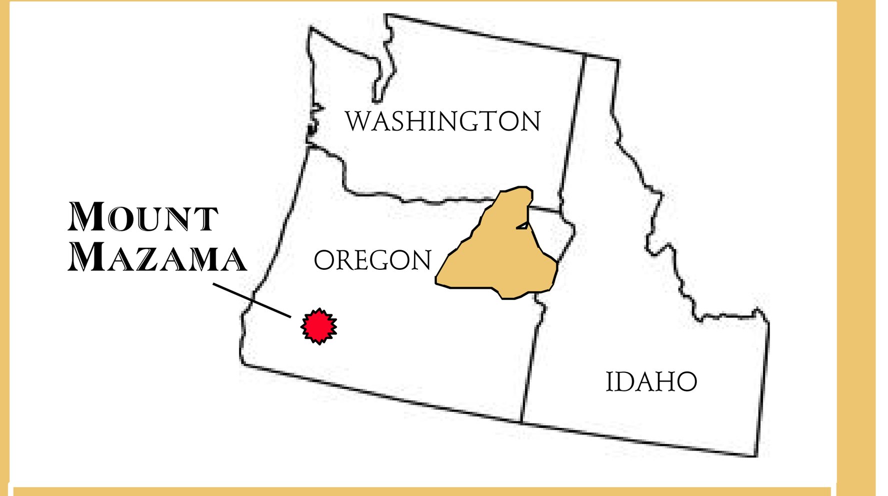

Figure 1. Location of the Blue Mountains physiographic province (shaded area) in eastern Oregon.

Figure 2. Landscape and profile of Endcreek and Pinuscreek pedons, respectively. Both are representative of soils and landforms. Mazama ash composes the upper 40 cm of the Endcreek pedon.

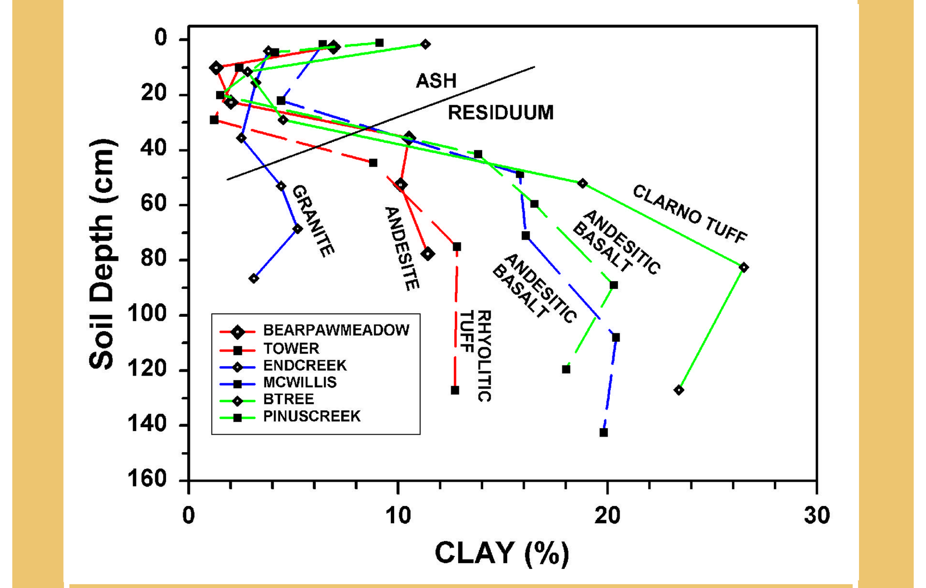

Figure 3. Clay percentage of pedons with depth. Parent materials of subsoil horizons (indicated as residuum) are indicated. Line color on figure indicates soil climatic regime: Red = Cryic/Udic, Blue = Frigid/Xeric, and Green = Frigid/Udic.

Table 1. Pedons selected for study.

Name	Soil Taxonomic Classification
Bearpawmeadow	Loamy-skeletal, isotic, Andic Eutrochrept
Tower	Ashy/loamy-skeletal, amorphic/mixed, Typic Vitricryand
Pinuscreek	Loamy-skeletal, isotic, Andic Hapludalf
Btree	Ashy/clayey, amorphic/smectitic, Alfic Udivitrand
McWillis	Medial/clayey-skeletal, glassy/isotic, Alfic Vitrixerand
Endcreek	Ashy/loamy-skeletal, glassy/isotic, Typic Vitrixerand

Name	Soil Climatic Regime	Elevation (m)	Slope/ Aspect (%/Deg)	Ash Mantle Thickness (cm)	Underlying Geology
Bearpawmeadow	Cryic/Udic	1682	35/350	35	Andesite
Tower	Cryic/Udic	1578	18/270	38	Rhyolitic Tuff
Pinuscreek	Frigid/Udic	1768	12/15	33	Andesitic Basalt
Btree	Frigid/Udic	1402	20/5	38	Clarno Tuff
McWillis	Frigid/Xeric	1597	45/45	48	Andesitic Basalt
Endcreek	Frigid/Xeric	1676	25/150	41	Granite

Introduction

Relative productivity of volcanic soils is generally high due to their unique physical and chemical properties. Soils in the Blue Mountains physiographic province of eastern Oregon (Figure 1) are developed in a wide variety of geologic materials overlain by a mantle of Mazama ash (Figure 2). Ash ranges up to 40 cm or more in thickness, depending on landscape stability, and controls many soil properties (water holding capacity, fertility, and erodibility) that influence forest management and productivity.

Soil climate of the Blue Mountains is elevation- and aspect-controlled. Elevations range from 1000 to 2000 m. Principal soil climatic regimes (SCR) mapped are frigid/xeric (F/X), frigid/udic (F/U), and cryic/udic (C/U) (Soil Survey Staff, 1999).

Pedons were selected from each of these soil climatic regimes. Micromorphology and associated soil properties were studied in order to better understand properties and relative differences in pedogenesis of the ash and underlying soil horizons in the Blue Mountains under selected soil climatic conditions.

Materials and Methods

Soils

Six pedons were selected from the three climatic regimes (Table 1). Pedons were representative of soils in relatively stable landforms with > 30 cm of ash and a variety of underlying parent materials. Soils were described and sampled by standard soil survey methodology (Soil Survey Staff, 1999).

Texture of the ash horizons is silt loam and moist hues are 7.5 or 10YR. Subsoil textures and colors vary depending on parent materials. Most geologic units forming subsoils are tied to Mesozoic (accretion and metamorphosis of complex Pacific Island arc terranes or subsequent granitic intrusions) and Cenozoic (episodes of andesitic, rhyolitic, and basaltic volcanism) eras.

Laboratory Analyses

Particle size analysis by pipet and sieving.

Selective dissolution of Fe, Al, and Si by sodium citrate dithionate, pyrophosphate, and acid oxalate extraction. Allophane percentage was estimated from selective dissolution extracts (Parfitt and Hemni, 1982; Parfitt, 1990).

Clay mineralogy was by x-ray diffraction analysis with pre-treatments to remove organic matter and Fe oxides.

Mineralogy of the coarse silt fraction was determined by mounting the soil with an epoxy cement and counting 300 grains using a petrographic microscope.

Thin sections were prepared by resin impregantion of natural fabric and described with terminology of Brewer (1976) and Bullock, et al. (1985).

Results and Discussions

Mineralogy and Other Properties

Ash is predominately fine and coarse silt in size, with clay ranging from 1.2 to 11.3 percent (Figure 3). These horizons contain up to 90 percent glass (Figure 4). Data suggest that eolian sorting of the pyroclastic material occurred following eruption of Mt. Mazama.

The pH depth function is similar in all soils (Figure 5). Organic horizons are generally most acidic (pH as low as 4.4) and mineral horizon pH generally ranges between 6 and 7. The slightly acidic pH in mineral horizons creates conditions suitable for stability of allophane and other non-crystalline minerals and suggests carbonic acid weathering.

Acid oxalate-extractable (0.5Fe+Al) in ash mantles is: C/U > F/U > F/X (Figure 6). This suggests that either (1) increasing moisture at higher elevations or on north-facing slopes (increasing precipitation or decreasing evapotransporation) increases ash weathering, or (2) landscapes in cryic sites are more stable, creating conditions for higher accumulations of secondary weathering products of ash.

Allophane ranges from 12 percent in the Bearpawmeadow pedon (SCR = C/U) to < 1 percent in the McWillis pedon (SCR = F/X). Allophane is typically highest in the Bw or Bw1 horizon indicating that the weathering conditions are greatest in upper mineral horizons. Acidic pH and higher organic C in A horizons likely result in formation of organo-metallic complexes of Fe and Al, preventing formation of inorganic non-crystalline weathering products such as allophane or ferrihydrite. The Al:Si ratio of allophane ranges from 1.4 to 2.3, with no correlation with SCR. Lower ratios (approaching 1:1 in some horizons) suggest only moderate silica leaching occurs in these soils.

Smectite, halloysite, and kaolinite are forming in addition to non-crystalline minerals in about some ash horizons (Table 2), with no correlation with SCR. These data suggest that solution silica concentrations are sufficient to support these minerals in addition to allophane. Mica, identified in the clay fraction in most ash and underlying horizons, is likely inherited from the underlying parent material.

Subsoils are composed of a variety of geologic materials (Table 1) with coarse fragments > 2 mm ranging from 10 to 95 percent. Glass and acid oxalate-extractable (0.5Fe+Al) decrease abruptly below the lithologic discontinuity indicating little mixing of ash with underlying materials (Figure 4 and Figure 6). The Tower pedon is an exception, with glass > 90 percent due to the vitrous rhyolitic tuff which composes the subsoil. Clay in subsoils (Figure 3) is generally greater than in ash, and ranges from < 5 percent in the granitic parent material (Endcreek pedon) to > 20 percent in the Clarno Tuff (Btree pedon).

Micromorphology (Ash Horizons)

Fabric is very porous, typical of Andisols (Figure 7), and is comprised of both interstitial pores within or channels and vughs between irregular-shaped aggregates. Most horizons have weak granular or subangular blocky structure, though fabric in the Endcreek pedon appears nearly massive.

Isotropic nature is due to the high percentage of glass composing the fabric. Coarse silt-sized crystalline minerals (components of the original ash deposit) are typically quartz and feldspar, with some hornblende. These minerals exhibit little to no weathering.

Upper soil horizons developed from ash in C/U sites principally have monic coarse/fine (c/f) distribution ratios, while fabrics in F/U and F/X sites grade toward porphyric c/f ratios (Figure 7). Coarsest grains in porphyric fabrics are principally sand-sized particles with a mineral composition similar to the subsoil parent material associated with that particular pedon. For example, slightly weathered basalt fragments in the McWillis pedon or biotite in the Endcreek pedon. Incorporation of subsoil materials likely occurs through soil mixing processes such as tree throw or faunal activity. Mixing is suggested by slight decreases in glass of ash horizons in these lower elevation sites relative to the Tower and Bearpawmeadow pedons (Figure 4). These facts support that pedons in the C/U SCR are more stable and/or less subjected to soil mixing.

Nodules in the Tower and Bearpawmeadow pedons (C/U SCR) have a redder hue and are denser than surrounding fabric (Figure 8). Crystalline grains (e.g., quartz and feldspars) in these concretions are similar in quantity to the surrounding fabric, though grains are slightly stratified in some nodules. Nodules have a sharp external boundary and are rounded to irregular in shape. No bridging or cementation between grains is apparent. Light microscopic identification of an isotropic cement in nodules composed primarily of glass and other fine-grained materials is problematic at best (Brewer, 1976; Flach, et al., 1973). Many nodules have a thin, concentric zone of darker material on the perimeter (Figure 8e), suggesting a higher concentration of a cementing agent on the exterior of the nodule.

Non-crystalline silica and allophane are possible cementing agents in these nodules. Deposition of these cements would occur during periods of dessication. Presence of durinodes is regarded as the initial stage in silica cementation (Flach, et al., 1969; Nettleton and Peterson, 1983). Silica, once adsorbed onto mineral surfaces, will provide a template for further adsorption during each wetting-drying cycle. The presence of smectite and halloysite in the clay would support the presence of excess solution silica. Allophane, present in concentrations > 10 percent in nodular ash horizons, has also been suggested as a possible cementing agent in soils (Wilson, et al., 1996; Freeland and Evans, 1993).

Micromorphology (Subsoil Horizons)

Subsoil horizon fabrics have c/f distribution ratios which range from porphyric to gerfuric depending on amount of sand-sized mineral grains (Figure 9). These grains are typically minerals and lithic fragments that compose the particular parent material. With the exception of Endcreek, all pedons have oriented clay in the subsoils. McWillis and Btree pedons have horizons with moderate to strongly oriented plasma fabric due to shrink-swell processes typically associated with smectite (Table 2). Tower, Bearpawmeadow, and Pinuscreek have patchy, moderate- to well-oriented clay in pores and channels. These argillans have likely formed under previous climatic conditions of the Holocene (Nettleton, et al., In press).

There was no evidence of movement and deposition of silica or allophane from the ash into these subsoils. This suggests that the pore size discontinuity between ash horizons and underlying soil material results in perching of water in the ash with subsequent desiccation and subsequent formation of nodules.

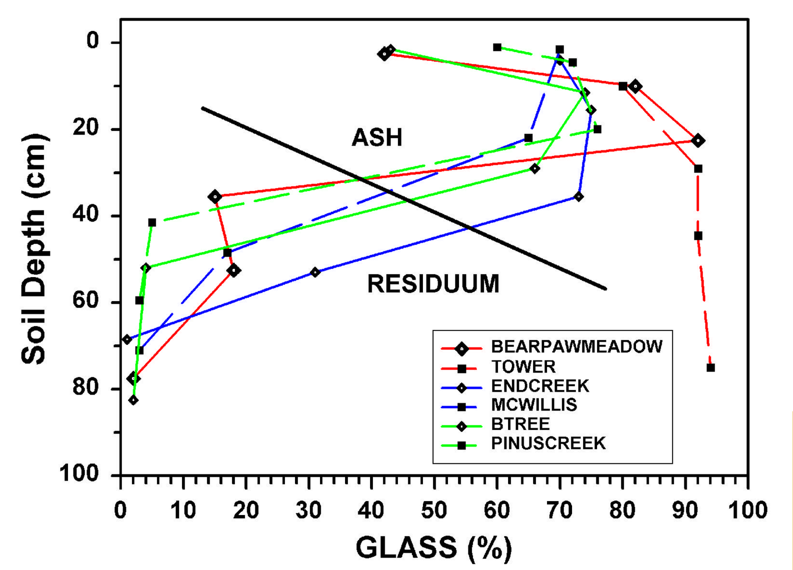

Figure 4. Percent glass composing the coarse silt fraction for pedons. Abrupt decrease in glass below lithologic discontinuity suggests little to no mixing of the upper and lower parent materials.

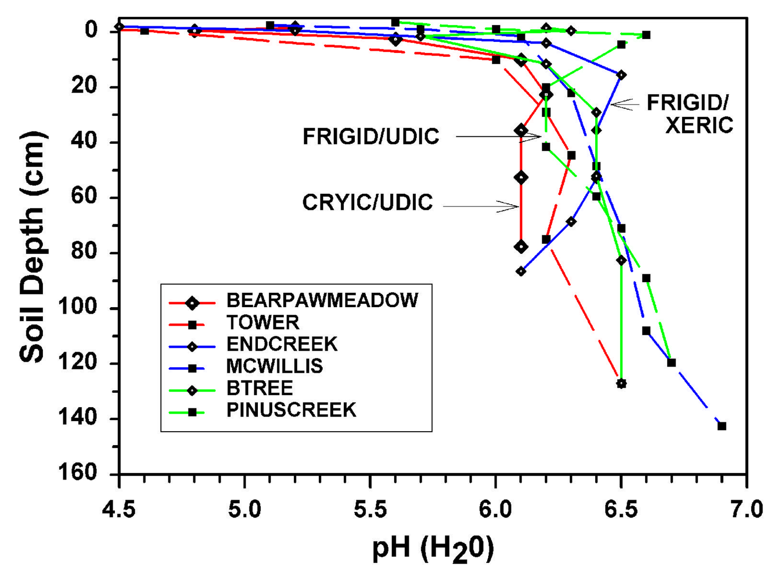

Figure 5. Soil pH for selected pedons with depth.

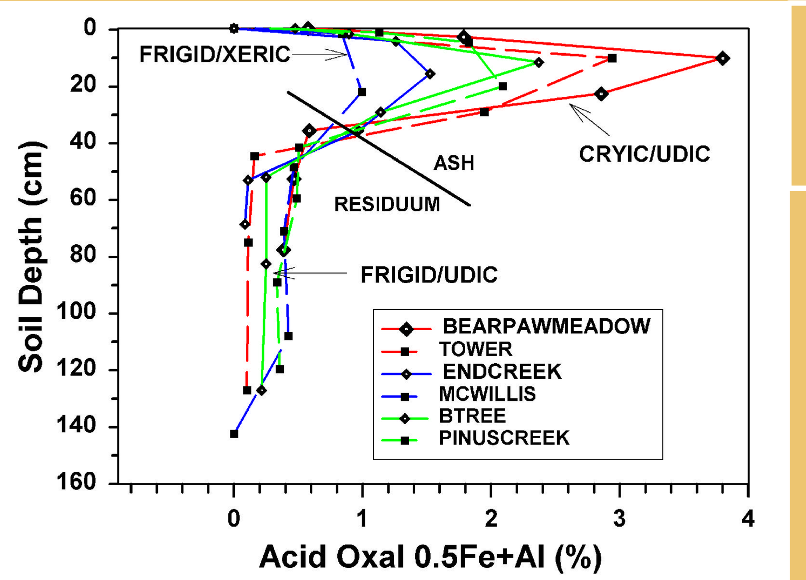

Figure 6. Acid oxalate-extractable (0.5Fe + Al) of selected pedons.

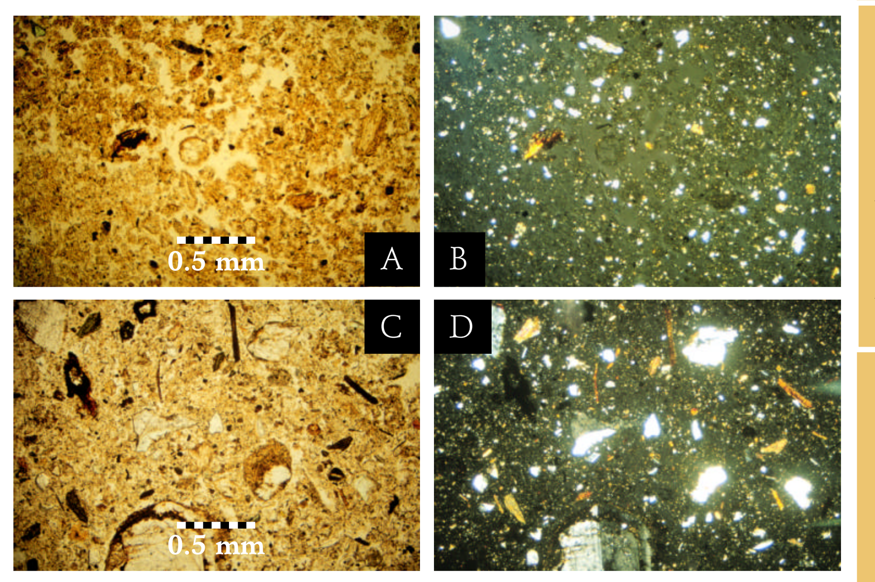

Figure 7. Photomicrographs (plane and cross-polarized light) of fabric from the Bw1 horizons from the Bearpawmeadow (A, B) and Endcreek (C, D) pedons.

Conclusions

Upper horizons of these pedons are principally composed of coarse and fine silt-sized Mazama ash. Glass composition ranges up to 90 percent. Abrupt decrease in glass below the ash mantle suggests insignificant mixing of ash with subsoil material in most soils. There is little evidence of minerals other than glass weathering in these upper horizons.

Higher concentration of acid oxalate extractable (0.5Fe+Al) and allophane in Tower and Bearpawmeadow pedons indicates that landscapes in the C/U SCR are more stable and/or have increased moisture resulting in greater weathering relative to the other SCRs.

Concentrations or nodules were identified in ash horizons of C/U SCR pedons. Possible cementing agents are silica or allophane. Only a small amount of an agent is required to bind a soil matrix (Chadwick, et al., 1987; Singh and Gilkes, 1993) and identification of the substance is not observable at the scale of the petrographic microscope.

While $Si(OH)_4$ is mobile in soil solution, no silica deposition is evident in subsoils of pedons. Subsoil horizons have oriented plasma fabrics and argillans that likely originate from a previous Holocene climate.

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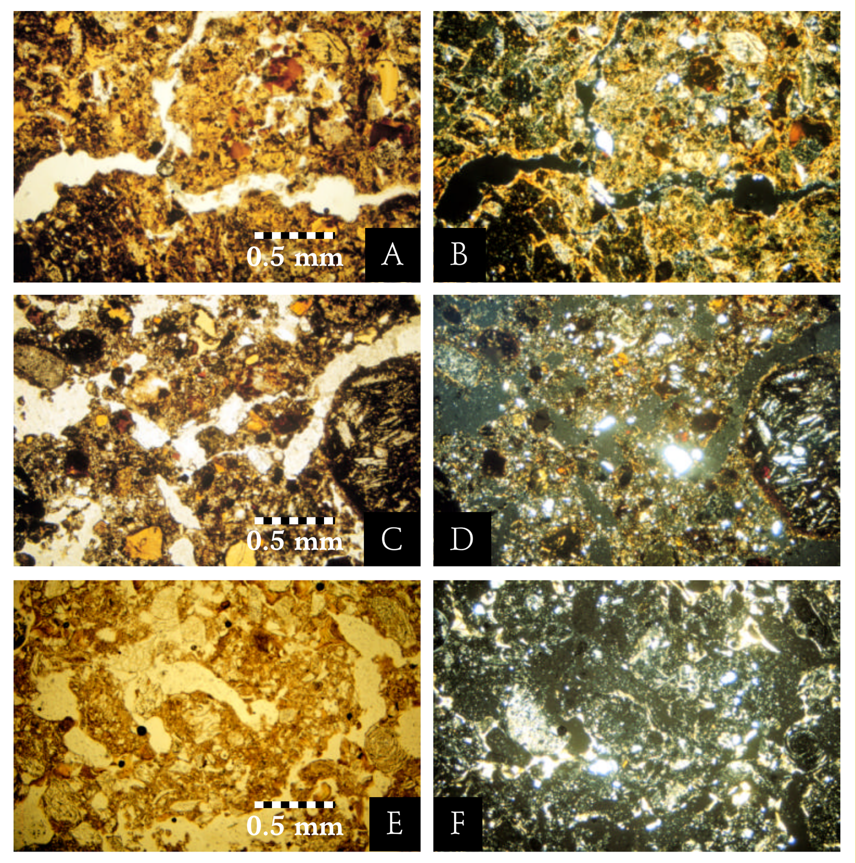

Figure 9. Photomicrographs of selected subsoil horizons (plane and cross-polarized light): 2Bwb of the Btree pedon (A, B); 2Eb of the McWillis pedon (C, D); and 2Bwb of the Tower pedon (E, F). Note the decrease in anisotropic plasma fabric between pedons.

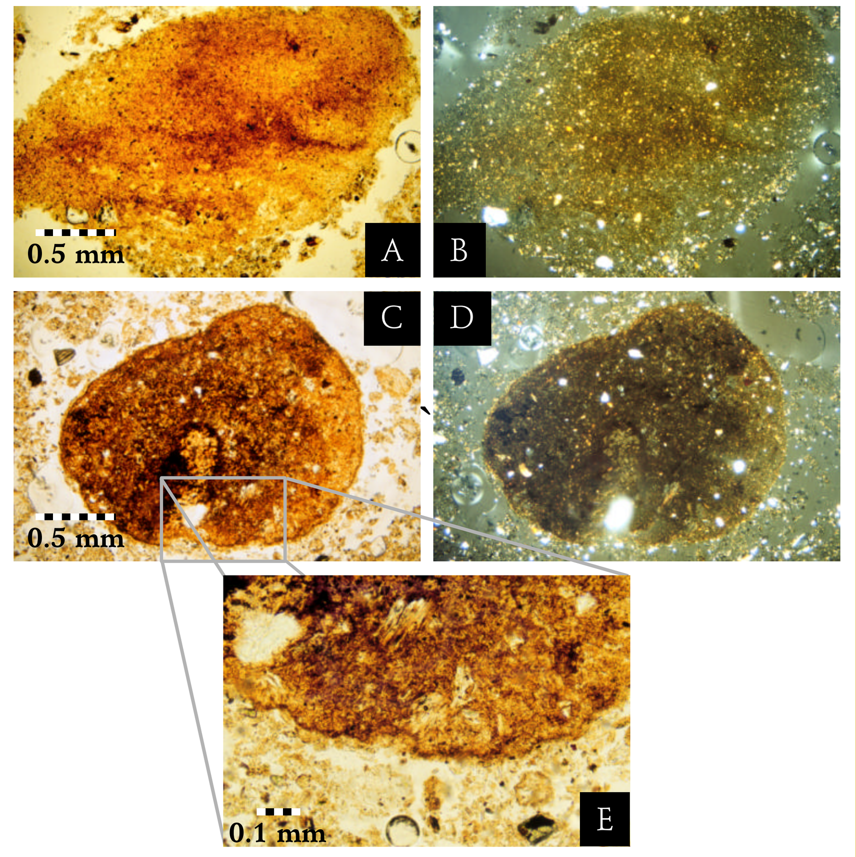

Figure 8. Photomicrographs of nodules (plane and cross-polarized light) found in the Bearpawmeadow (A, B) and Tower (C, D) pedons. Photo E represents circled area in photo C. (Bar scale on photos = 0.5 mm; except photo E, where scale = 0.1 mm.)

Table 2. Mineralogy of clay fraction. (Semiquantitative estimates of peaks identified: X = 0-3%; XX = 3-10%.)

Name	Horizon	SM[1]	VR[1]	MI[1]	KH[1]	KK[1]
Bearpawmeadow	A	X		X		X
	Bw2 [2]					
	2Bwb	XX		X	XX	X
Tower	Bw1 [2] & Bw2 [2]					
	2Bwb	XX		X	XX	
Pinuscreek	A		X			X
	Bw				X	
	2Bt	X		X		XX
Btree	A	X		X		
	Bw2			X		
	2Btb	XX		X	XX	
McWillis	A [2]					
	Bw			X		
	2Bt2b	X		X	XX	
Endcreek	A [2]					
	Bw2 & 2BC	X		XX	X	

[1] SM-smectite, VR-vermiculite, MI-illitic mica, KH-halloysite, KK-kaolinite [2] No peaks on diffraction patterns (non-crystalline).